INDOOR AIR QUALITY ASSESSMENT

Amesbury Fire Department
17 School Street
Amesbury, Massachusetts

Prepared by:
Massachusetts Department of Public Health
Bureau of Environmental Health Assessment
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Background/Introduction

At the request of Deputy Chief William Shute of the Amesbury Fire Rescue Department (AFRD), an indoor air quality assessment was done at the Amesbury Fire Station (the station), 17 School Street, Amesbury, Massachusetts. This assessment was conducted by the Massachusetts Department of Public Health (MDPH), Bureau of Environmental Health Assessment (BEHA). On March 22, 2002, a visit was made to the station by Cory Holmes, of BEHA's Emergency Response/Indoor Air Quality (ER/IAQ) Program, to conduct an indoor air quality assessment. Deputy Chief Shute accompanied Mr. Holmes during the assessment.

The station is a two-story, red brick building that was constructed in 1927. The roof consists of rubber membrane with a small peak covered with asphalt shingles. Deputy Chief Shute reported that the rubber membrane was replaced approximately six years ago. The first floor contains five-engine bays, storerooms and dispatch area. The second floor contains bedrooms (for overnight staff), office space and a day room/lounge, referred to by AFRD staff as "the front room". The front of the building has five garage doors that enclose each engine bay (see cover photo). An enclosed stairwell connects the engine bay to the front room on the second floor. A fire pole connecting the second floor to the engine bay is located in the front room. New double paned energy efficient windows were installed in 1978. Windows are openable throughout the building.

Methods

Air tests for carbon dioxide, carbon monoxide, temperature and relative humidity were taken with the TSI, Q-Trak, IAQ Monitor. Air tests for ultrafine particulates were taken with the TSI, P-Trak ™ Ultrafine Particle Counter Model 8525.

Results

The station is staffed 24 hours a day, seven days a week and has an employee population of approximately 7-9. Approximately 10-15 members of the public visit the station on a daily basis. Tests were taken under normal operating conditions. Test results for general air quality parameters (i.e., carbon dioxide, temperature and relative humidity) appear in Tables 1-2. Test results for ultrafine particulates and carbon monoxide are listed in Tables 3-4.

Discussion

Ventilation

It can be seen from the tables that carbon dioxide levels were below 800 parts per million (ppm) in all areas surveyed, indicating adequate air exchange under normal occupancy conditions. Ventilation is provided by three rooftop air handling units (AHUs). Each AHU is connected to wall-mounted air diffusers by ducts. Return vents located throughout the building (see Picture 4) draw air from interior areas back to each AHU via ductwork.

Wall-mounted thermostats control the HVAC system. The thermostats have fan settings of "on" and "auto" (see Picture 1). All thermostats were set to the "auto" setting during the assessment. The automatic setting on the thermostat activates the HVAC system at a preset temperature. Once the thermostat reaches a preset temperature, the HVAC system is deactivated until the temperature drops below the heating set point. Therefore, no mechanical ventilation is provided until the thermostat re-activates the system. No airflow from supply or return vents was detected during the assessment. Without dilution and removal by the HVAC system, pollutants can build-up in occupied spaces and lead to indoor air quality complaints.

To maximize air exchange, the BEHA recommends that both supply and exhaust ventilation operate continuously during periods of occupancy. In order to have proper ventilation with a mechanical ventilation system, the systems must be balanced to provide an adequate amount of fresh air to the interior of a room while removing stale air from the room. The date of the last balancing of these systems was not available at the time of the assessment. It is recommended that existing ventilation systems be re-balanced every five years to ensure adequate air systems function (SMACNA, 1994).

The Massachusetts Building Code requires a minimum ventilation rate of 20 cubic feet per minute (cfm) per occupant of fresh outside air or have openable windows in each room for office areas; 30 cfm for dormitories (SBBRS, 1997; BOCA, 1993). The ventilation must be on at all times that the room is occupied. Providing adequate fresh air ventilation with open windows and maintaining the temperature in the comfort range during the cold weather season is impractical. Mechanical ventilation is usually required to provide adequate fresh air ventilation.

Carbon dioxide is not a problem in and of itself. It is used as an indicator of the adequacy of the fresh air ventilation. As carbon dioxide levels rise, it indicates that the ventilating system is malfunctioning or the design occupancy of the room is being exceeded. When this happens a buildup of common indoor air pollutants can occur, leading to discomfort or health complaints. The Occupational Safety and Health Administration (OSHA) standard for carbon dioxide is 5,000 parts per million parts of air (ppm). Workers may be exposed to this level for 40 hours/week based on a time weighted average (OSHA, 1997).

The Department of Public Health uses a guideline of 800 ppm for publicly occupied buildings. A guideline of 600 ppm or less is preferred in schools due to the fact that the majority of occupants are young and considered to be a more sensitive population in the evaluation of environmental health status. Inadequate ventilation and/or elevated temperatures are major causes of complaints such as respiratory, eye, nose and throat irritation, lethargy and headaches (see Appendix I).

Temperature measurements ranged from 62^{o} F to 73^{o} F, which were below the BEHA recommended comfort range in several areas. The BEHA recommends that indoor air temperatures be maintained in a range of 70^{o} F to 78^{o} F in order to provide for the comfort of building occupants. Complaints of excessive cold were expressed to BEHA staff, specifically in the main lobby, which is unheated. Several other complaints of uneven heating and cooling were also reported. In many cases concerning indoor air quality, fluctuations of temperature in occupied spaces are typically experienced, even in a building with an adequate fresh air supply.

The relative humidity in the building ranged from 20 to 26 percent, which was below the BEHA recommended comfort range. The BEHA recommends a comfort range of 40 to 60 percent for indoor air relative humidity. Relative humidity levels would be expected to drop during the winter months due to heating. The sensation of dryness and irritation is common in a low relative humidity environment. Low relative humidity is a very common problem during the heating season in the northeast part of the United States.

Microbial/Moisture Concerns

The building has reportedly experienced problems with water penetration, most notably the second floor ceiling (see Pictures 2 & 3). No obvious sources of interior moisture problems were noted. A number of conditions were observed which could potentially provide a means of water penetration into the building. Sections of the roof edge had no gutters or downspouts (see Pictures 4 & 5). Lack of proper roof drainage allows rainwater to run down the side of the building and pool on the ground at the base of the building against exterior walls (see Picture 6). The freezing and thawing action of water during winter months can create cracks and fissures in the foundation. Over time, this process can undermine the integrity of the building envelope and provide a means of water entry into the building.

BEHA staff observed building envelope breaches, which could also provide a source of water penetration. Exterior walls of the building have problems with water intrusion. Water intrusion through exterior brick was evident by the presence of efflorescence (e.g. mineral deposits) and water-damaged building materials. As moisture penetrates and works its way through mortar around brick, it leaves behind these characteristic mineral deposits. A perimeter inspection of the exterior of the building also revealed missing, damaged and crumbling mortar around brickwork (see Pictures 7 & 8). These conditions are breaches of the building envelope and provide a means for water entry into the building.

Pooling water was observed in a number of areas on the roof (see Picture 9). The freezing and thawing of water during winter months can lead to roof leaks and subsequent water penetration into the interior of the building. Pooling water can also become stagnant, which can lead to mold and bacterial growth, which can be introduced into the building by rooftop fresh air intakes. In addition, stagnant pools of water can serve as a breeding ground for mosquitoes.

Each of these conditions compromises the integrity of the building envelope and can provide a means for water penetration into the building. Repeated water damage to porous building materials (e.g., wallboard, ceiling tiles, carpeting) can result in microbial growth. The American Conference of Governmental Industrial Hygienists (ACGIH) recommends that porous building materials be dried with fans and heating within 24 hours of becoming wet (ACGIH, 1989). If not dried within this time frame, mold growth may occur. Once mold has colonized porous materials, they are difficult to clean and should be removed.

Vehicle Exhaust

Under normal conditions, a firehouse can have several sources of environmental pollutants present from the operation of fire vehicles. These sources of pollutants can include:

- Vehicle exhaust containing carbon monoxide and soot;
- Vapors from diesel fuel, motor oil and other vehicle liquids which contain volatile organic compounds;
- Water vapor from drying hose equipment;
- Rubber odors from new vehicle tires; and
- Residues from fires on vehicles, hoses and fire-turnout gear.

Of particular importance is vehicle exhaust. In order to assess whether contaminants generated by diesel engines were migrating into occupied areas of the station, measurement for airborne particulates in combination with carbon monoxide measurements were used to pinpoint the source of combustion products.

The use of fossil fuel-powered equipment (e.g., propane heaters, diesel or gasoline-powered vehicles, acetylene welding, etc.) can produce carbon monoxide. Using carbon monoxide solely to detect sources of combustion pollutants has a major drawback. If the source of combustion pollutants is allowed to dilute in a large volume of air within a building, carbon monoxide concentrations may decrease below the detection limits of equipment. The process of combustion produces airborne liquids, solids and gases (NFPA, 1997). The measurement of airborne particulates, in combination with carbon monoxide measurements, can be used to pinpoint the source of combustion products. Measurements for ultrafine particles (UFPs) [particles measuring 0.02 micrometers (μm) to 1 μm in diameter] as well as carbon monoxide were taken.

The process of combustion produces a number of pollutants, depending on the composition of the material. In general, common combustion emissions can include carbon monoxide, carbon dioxide, water vapor and smoke. Of these materials, carbon monoxide can produce immediate, acute health effects upon exposure. The MDPH established a corrective action level concerning carbon monoxide in ice skating rinks that use fossil-fueled ice resurfacing equipment. If an operator of an indoor ice rink measures a carbon monoxide level over 30 ppm, taken 20 minutes after resurfacing within the rink, that operator must take actions to reduce carbon monoxide levels (MDPH, 1997).

The US Environmental Protection Agency has established National Ambient Air Quality Standards (NAAQS) for exposure to carbon monoxide in outdoor air. Carbon monoxide levels in outdoor air must be maintained below 9 ppm over a twenty-four hour period in order to meet this standard (US EPA, 2000). Measurements of carbon monoxide (10 ppm) exceeded the NAAQS taken in occupied areas above the engine bay after diesel engine operation.

The combustion of fossil fuels can produce particulate matter that is of a small diameter (<10 μm), which can penetrate into the lungs and subsequently cause irritation. For this reason a device that can measure particles of a diameter of 10 μm or less was also used to identify pollutant pathways from the engine bays into occupied areas. Inhaled particles can cause respiratory irritation.

The instrument used by the BEHA to conduct air monitoring for UFPs counts the number of particles that are suspended in a cubic centimeter (cm^3) of air. This type of air monitor is useful as a screening device, in that it can be used as a tracker to identify the source of airborne pollutants by counting the actual number of airborne particles. The source of particle production can be identified by moving the ultrafine particle counter (UPC) through a building towards the highest measured concentration of airborne particles.

Measured levels of particles/cm^3 of air increase as the UPC is moved closer to the source of particle production. While this equipment can ascertain whether unusual sources of ultrafine particles exist in a building or that particles are penetrating through spaces in doors or walls, it cannot be used to quantify whether the NAAQS PM_{10} standard was exceeded. The primary purpose of these tests at the station was *to identify and reduce/prevent pollutant pathways*. Air monitoring for ultrafine particles was conducted in the engine bay, areas adjacent and above the engine bay and around doors, utility holes and other areas, which may be directly impacted from close proximity to the engine bay. For comparison, measurements in areas away from the engine bay, outdoors and other areas not believed to be effected were also conducted. The highest readings for ultrafine particulates were measured in the engine bay during diesel engine operation, which would be expected during the normal operation of motor vehicles indoors. Measurements recorded over outside (background) levels indicate a combustion source of UFPs.

The station is not equipped with a mechanical exhaust system to remove exhaust from the engine bays during vehicle idling, which can allow vehicle exhaust emissions to accumulate within the station. A number of pathways for vehicle exhaust and other pollutants to move from the engine bays into occupied areas on both the first and second floors were identified (see Figure 1).

- Engine bay exterior doors had significant spaces around them from which drafts could be felt and light could be seen (see Picture 10). Drafts can pressurize the engine bays, forcing pollutants into occupied areas through any available pathways.
- Light was seen penetrating around the access hatch that separates the fire pole on the second floor from the engine bay, indicating a potential pathway (see Pictures 11 & 12).

- Another possible pathway for exhaust emissions is through utility holes. The ceiling and walls of the engine bays are penetrated by holes for utilities. These spaces around utility pipes can present potential pathways into occupied areas if they are not sealed airtight.

Each of these conditions present a pathway for air to move from the engine bays to occupied areas of the station. Elevated levels of UFPs and noticeable exhaust emission odors were detected in most of the occupied areas of the second floor during and after operation of fire fighting vehicles (see Tables). In order to explain how engine bay pollutants may be impacting the second floor and adjacent areas, the following concepts concerning heated air and creation of air movement must be understood.

- ♦ Heated air will create upward air movement (called the stack effect).
- ♦ Cold air moves to hot air, which creates drafts.
- ♦ As heated air rises, negative pressure is created, which draws cold air to the equipment creating heat (e.g., vehicle engines).
- ♦ Combusted fossil fuels contain heat, gases and particulates that will rise in air. In addition, the more heated air becomes, the greater airflow increases.
- ♦ The operation of HVAC systems (including rest room exhaust vents) can create negative air pressure, which can draw air and pollutants from the engine bays.

Each of these concepts has influence on the movement of odors to the second floor and dispatch office. As motor vehicles operate indoors, the production of vehicle exhaust in combination with cold air moving from outdoors through open exterior doors into the warmer engine bays can place the garage under positive pressure. Positive pressure within a room will force air and pollutants through spaces around doors, utility pipes and other holes in walls, doors and ceilings. To reduce airflow into the second floor, sealing of these pollutant pathways should be considered.

In order to overcome the creation of airflow through the discussed pathways, the introduction of fresh air and exhaust by mechanical means may be employed. The Massachusetts Building Code requires a minimum ventilation rate of 1.5 cubic feet per minute (cfm) per square foot of floor space of fresh outside air (SBBRS, 1997; BOCA, 1993) for garages. The use of mechanical exhaust ventilation to create negative air pressure in engine bays while the fire station is occupied can serve to prevent/limit odor penetration into the second floor.

Finally, a damaged sewer vent pipe was observed on the peaked roof of the station. Reports of periodic sewer gas odors as well as frequent backups of sewage into the bathroom shower were reported by occupants.

Conclusions/Recommendations

In view of the findings at the time of the visit, the following recommendations are made:

1. In order to prevent the migration of vehicle exhaust emissions into occupied areas, mechanical exhaust ventilation should be installed to create negative pressure in the engine bays.
2. Keep all doors and windows accessing engine bays closed at all times.
3. Consider replacing engine bay doors or have them repaired to eliminate spaces between doors and frames. Ensure tightness by monitoring for light penetration and drafts around doorframes.
4. Consider replacing fire pole access hatch with an alternate design that forms an airtight seal to prevent pollutant pathways into occupied areas. If not feasible, seal hatch on all sides with foam tape, and/or weather-stripping. Ensure tightness by monitoring for light penetration and drafts.
5. Ensure all utility holes are properly sealed in both the engine bay and their terminus to eliminate pollutant paths of migration.
6. Work with Amesbury town officials to develop a preventative maintenance program for all HVAC equipment department wide.
7. Change filters for HVAC equipment as per the manufacturer's instructions or more frequently if needed. Examine HVAC equipment periodically for maintenance and function.
8. To maximize air exchange, the BEHA recommends that both supply and exhaust ventilation operate continuously during periods of building occupancy independent of thermostat control (excluding engine bay exhaust system). Consider setting

thermostat controls to the fan's "on" position to provide constant supply and exhaust ventilation.

9. Consider having the ventilation systems balanced by an HVAC engineer.

10. For buildings in New England, periods of low relative humidity during the winter are often unavoidable. Therefore, scrupulous cleaning practices should be adopted to minimize common indoor air contaminants whose irritant effects can be enhanced when the relative humidity is low. To control for dusts, a HEPA filter-equipped vacuum cleaner in conjunction with wet wiping of all surfaces is recommended. Drinking water during the day can help ease some symptoms associated with a dry environment (throat and sinus irritations).

11. Examine the feasibility of installing a gutter/downspout system to portions of the building where they are currently lacking (e.g., the peaked roof and communications).

12. Consider having the building re-pointed to prevent further water damage and to preserve structural integrity of the building.

13. Inspect roof for proper drainage; consider consulting a building engineer about possible options to eliminate water pooling on roof.

14. Repair/replace damaged vent pipe on roof; have the plumbing system inspected by a licensed plumbing firm to ensure proper function.

15. Replace water-damaged ceiling tiles.

References

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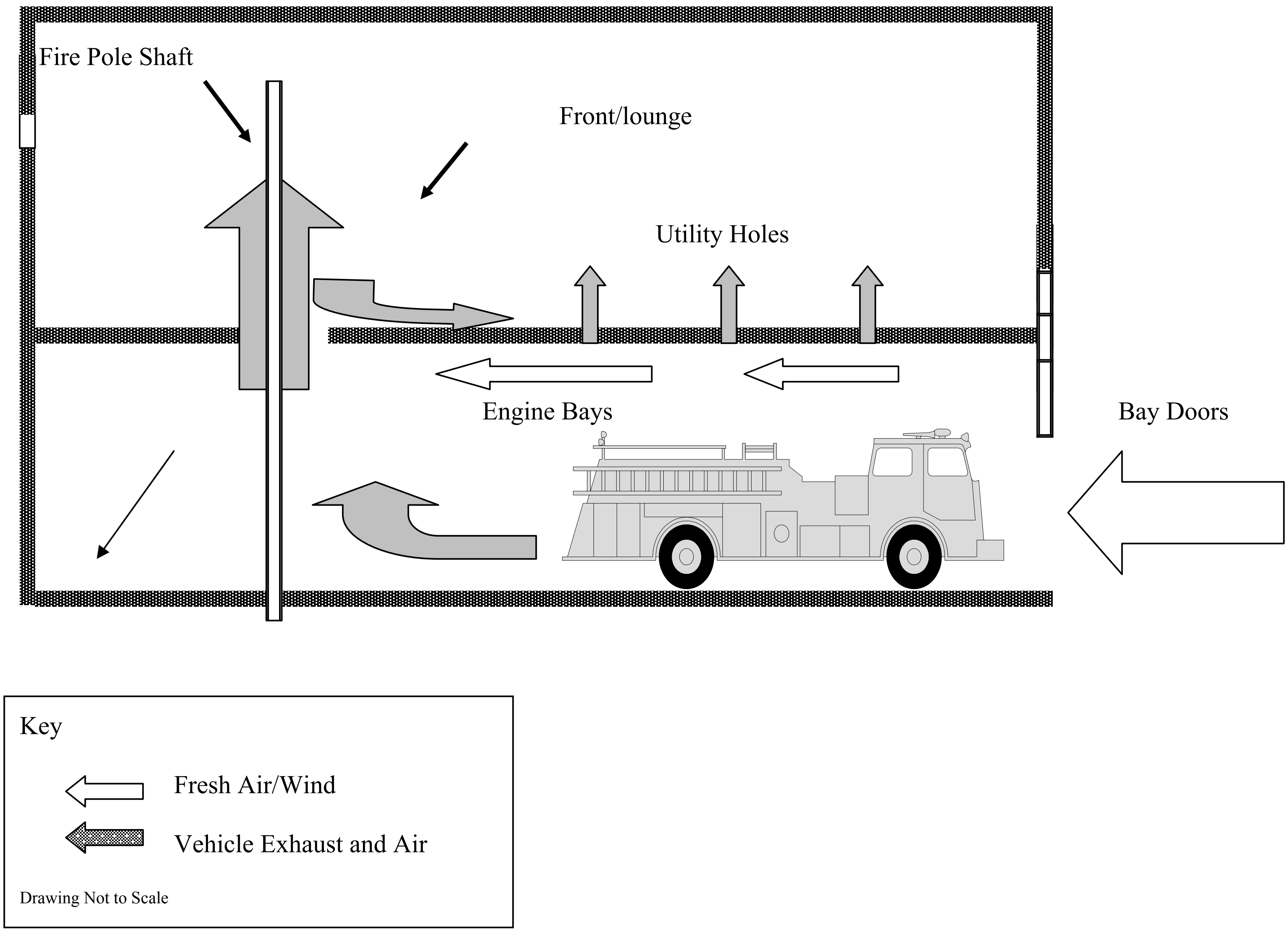
Figure 1 **Potential Pathways of Air and Pollutant Movement from Engine Bays through Holes in Ceilings and Spaces around Door Frames**



Picture 1

Wall-Mounted Thermostat - Note Fan Switch Set to "Auto"

Picture 2

Water-Damaged Ceiling Tiles

Picture 3

Water-Damaged Ceiling Tiles

Picture 4

Peaked Roof with no Gutters/Downspouts, Note Roof Drains Directly onto AHU

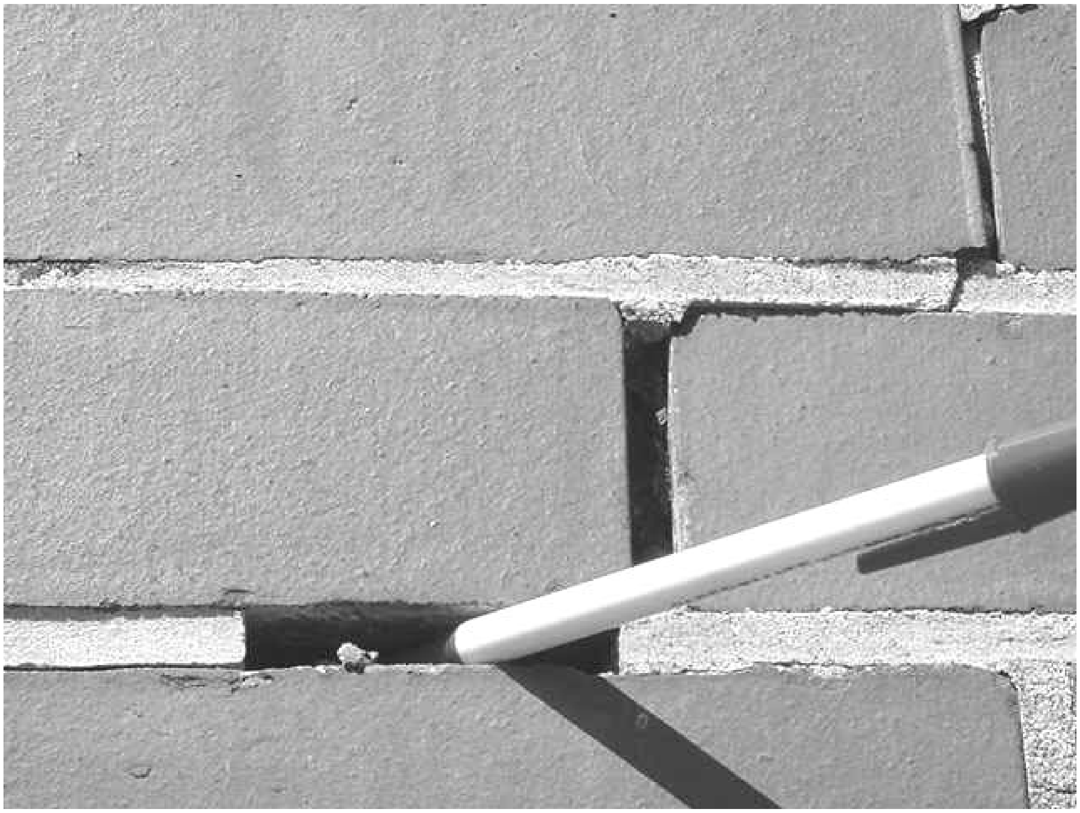
Picture 5

Water Runoff from Communications Portion of Building

Picture 6

Pooling Water against the Communications Exterior Wall

Picture 7



Missing/Damaged Mortar around Bricks, Pen Inserted to Show Depth

Picture 8

Missing/Damaged Mortar around Bricks Exposing Metal of Window Frame

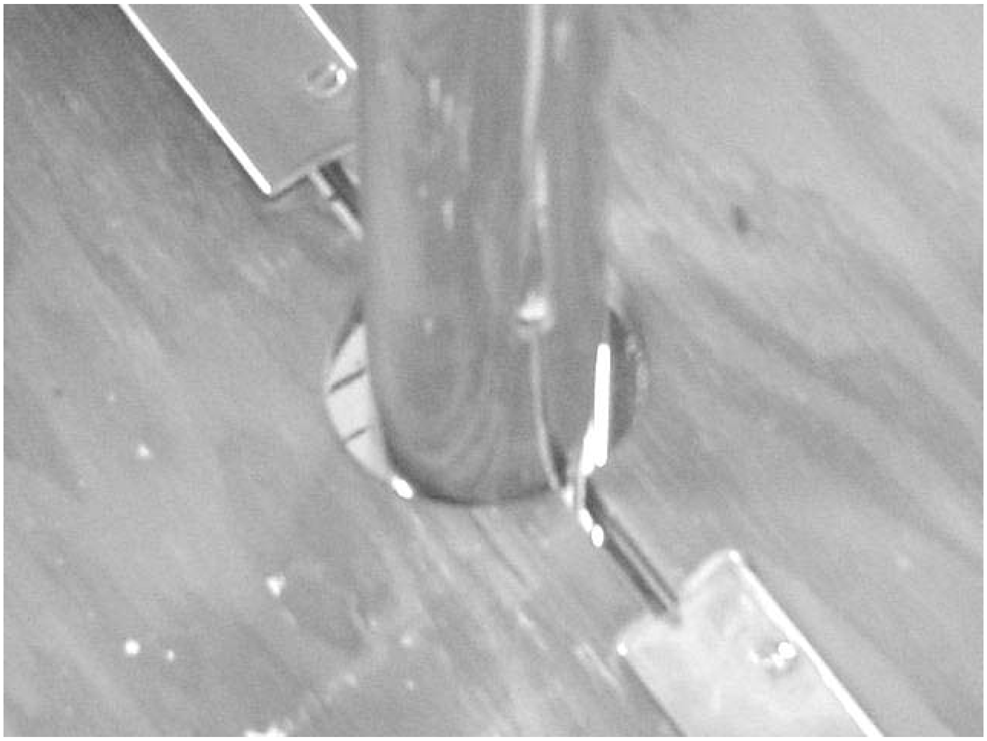
Picture 9

Pooling Water on Roof - Note Lack of Roof Drains

Picture 10

Spaces around Engine Bay Doors

Picture 11



Spaces around Fire Pole Access Hatch (view from top)

Picture 12

Spaces around Fire Pole Access Hatch (view from underneath/engine bay)

TABLE 1

Indoor Air Test Results – Amesbury Fire Department Headquarters, Amesbury, MA – March 22, 2002

Location	Carbon Dioxide *ppm	Temp °F	Relative Humidity %	Occupants in Room	Windows Openable	Ventilation Intake	Ventilation Exhaust	Remarks
Outside (Background)	355	34	13					NW wind 15-20 mph gusts of 25 mph, cold and clear
Perimeter/Roof Inspection Notes								No gutters/downspouts on communications and peaked roof, standing water/moss growth on roof, water splashing against building, missing damaged mortar around brick, substantial spaces near window flashings, sewer vent pipe on roof damaged
Training	582	71	26	2	No	Yes	Yes	
Deputy Chief Shute Office	641	71	26	0	Yes	Yes	No	
Chief's Office	750	72	26	2	Yes	Yes	No	Photocopier
Lt. Room	682	73	24	0	Yes	Yes	No	Door open
Hallway	675	72	23	0	No	Yes	Yes	
Bedroom 1	616	70	20	0	Yes	Yes	No	Ceiling fan

*** ppm = parts per million parts of air**

CT = ceiling tiles

Comfort Guidelines

Carbon Dioxide -	< 600 ppm = preferred
	600 - 800 ppm = acceptable
	> 800 ppm = indicative of ventilation problems
Temperature -	70 - 78 °F
Relative Humidity -	40 - 60%

TABLE 2

Indoor Air Test Results – Amesbury Fire Department Headquarters, Amesbury, MA – March 22, 2002

Location	Carbon Dioxide *ppm	Temp °F	Relative Humidity %	Occupants in Room	Windows Openable	Ventilation		Remarks
						Intake	Exhaust	
Hallway					No	Yes	Yes	Return grill missing
New Addition	612	67	23	0				Under construction
Bedroom 3	615	69	25	0	No	Yes	No	Ceiling fan, Window sealed by new addition
Bathroom	607	70	26	0	No	No	Yes	Reports of frequent sewage backups-shower
Front Room	645	70	25	7	Yes	Yes	Yes	Fire pole access-spaces into engine bay
Fire Alarm Support	633	71	24	1	Yes	Yes	No	CT-8, missing CT/water damage
Dispatch/Comm Center	534	71	22	1	Yes	No	No	Window-mounted AC
Engine Bay	528	71	21	0	No	No	No	Large spaces around engine bay doors, no mechanical exhaust ventilation system
Lobby	399	62	24	0	Yes	No	No	No mechanical ventilation or heat

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Relative Humidity -	40 - 60%

TABLE 3

Indoor Air Test Results – Amesbury Fire Department, Amesbury, MA – March 22, 2002

Location	Ultrafine Particulates p/cc	Carbon Monoxide ppm
Outside (Background)	4,200-6,500	
Engine Bay	70,000-119,000	3-5
Front Room	43,500-44,600	2-6
Fire Access Pole (opening in front room)	47,000-200,000	4-6
Upper Stairwell	13,200-19,500	1-2
Lower Stairwell	11,400-24,000	1-2
Dispatch	9,700-18,900	1-2
Training	28,000-34,000	2-10
Deputy Shute's Office	32,000-34,100	2-10
Chief's Office	38,000-52,800	2-10

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p/cc = particles per cubic centimeter of air
CT = ceiling tiles

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Relative Humidity -	40 - 60%

TABLE 4

Indoor Air Test Results – Amesbury Fire Department, Amesbury, MA – March 22, 2002

Location	Ultrafine Particulates p/cc	Carbon Monoxide ppm
Lt. Room	36,000-52,000	2-10
Hallway	34,000-49,500	2-9
New Addition	17,800-42,000	3-6
Bedroom 1	15,900-24,000 (window open)	1-6
Hallway	20,400-40,000	2-7
Bedroom 3	43,800-46,000	3-7
Lobby	8,700	1

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p/cc = particles per cubic centimeter of air
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